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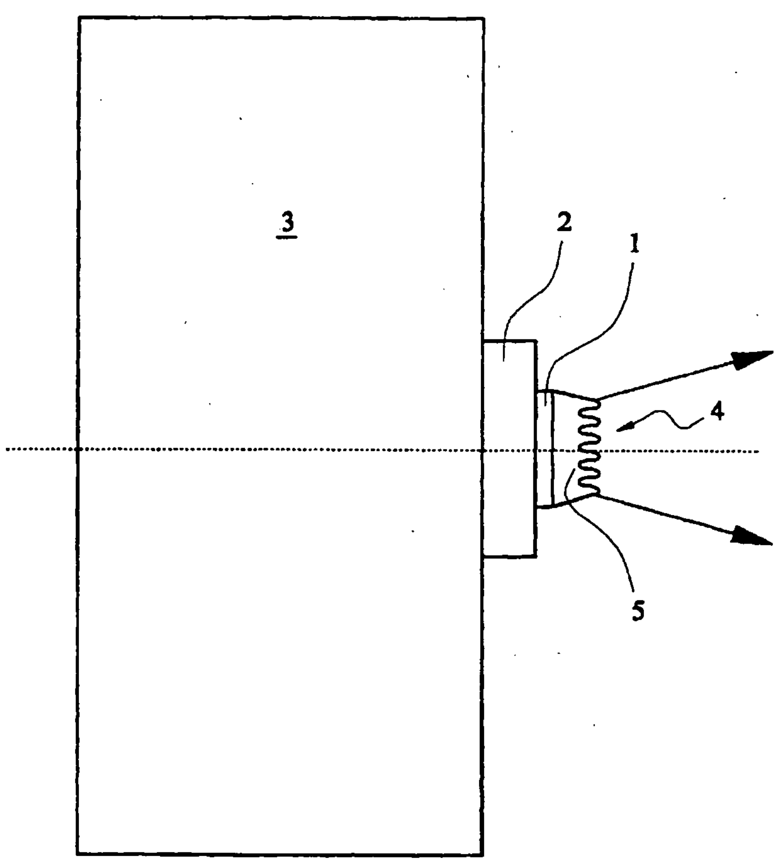
(54) Title: LIGHT EMITTING DIODES



(57) Abstract: To increase the amount and/or directionality of light from a light emitting diode (LED) 1 supported on a substrate 2, the side of the diode remote from the substrate is provided with an additional layer 5 in which is formed a diffractive (grating) or interference (Fresnel lens) optical elemental 4 of varying thickness. The construction is particularly useful in the infra-red, where the thickness variation cannot be built into the LED structure itself. Layer may be formed during manufacture of the LED, or secured thereto by an optically thin layer of adhesive.

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— *of inventorship (Rule 4.17(iv)) for US only*

Published:
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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Light Emitting Diodes

The present invention relates to light emitting diodes (LEDs). It is particularly but not exclusively directed to LEDs which emit electromagnetic radiation through a side surface of the semiconductor structure which lies parallel to the diode junction. LEDs are commonly formed by deposition of material upon a semiconductor substrate, or by implantation or other modification of material within a semiconductor substrate.

Light emitting diodes have many applications, including telecommunications, spectroscopy and gas sensing. A recent development is that of room temperature infra-red light emitting diodes which cover the 3 to 12 micron spectral region where gases such as carbon dioxide, carbon monoxide, nitrogen oxides, sulphur oxides and carbohydrates have strong selective absorption bands enabling quantitative gas detection.

It is clearly advantageous to be able to maximise the optical output power of a light emitting diode. For example in infra-red gas sensing at low concentrations, such as in the parts-per-billion (ppb) to parts-per-million (ppm) range, the output powers of existing devices are not sufficient to provide conditions allowing a good signal-to-noise ratio.

A major reason for the low output power is the inefficiency in transmitting the light generated at the diode junction to the exterior, and a principal cause thereof is total internal reflection within the device. As is well known, light can only pass from an optically dense medium (high real refractive index of value n) to air (where n is nominally unity) if its angle of incidence is no greater than $\sin^{-1}(1/n)$, and it otherwise undergoes total internal reflection. Thus, for a side emitting LED based on indium antimonide (InSb), where $n = 4$, and assuming a uniform angular distribution of optical emission from the diode junction over a solid hemispherical angle 2π towards a planar side surface of the device, only 3% of the light emitted within the junction is directly transmitted through the planar surface.

Additionally, the latter small amount of light is emitted over a large solid angle. It is commonly difficult or impractical to collect light within a large solid angle by the use

of external optics, thereby adding to the disadvantages when a directed beam of light is required.

The present invention is directed to reducing the amount of light being lost due to reflection within LEDs, and/or to increasing the directionality of light emitted from LEDs. The first step should reduce the optical output power necessary from the diode junction for a given device overall output, or should increase the device overall output for a given output from the diode junction. The second step should reduce the optical output power necessary from the diode junction for a given device output in a predetermined direction, or should increase the device output in a predetermined direction for a given output from the diode junction.

For LEDs emitting in the visible region it is known to form an integral contoured interference or diffractive element, for example a Fresnel lens or grating provided by differing optical thicknesses, in the top region of the LED active layer itself. This is possible in that the thickness of the diffractive element to be accommodated at visible wavelengths is significantly less than the thickness of this top region, which is normally 2 microns or less.

However, for infra-red emitting LEDs, where the wavelength can be around 10 times as great, typically 5 to 12 microns, the correspondingly greater thickness of the diffractive element makes it very difficult or impossible for it to be accommodated in the LED structure itself without destroying the LED.

It is also known to provide a textured surface on the top surface of an LED (remote from its substrate) and the top surface of the substrate itself. A rear reflector is additionally provided on the substrate. Thus light from the LED active layer undergoes a series of reflections from within the LED and the substrate until it reaches an incident angle at which it can leave through the device surface. See, for example, Composite Semiconductor 6(4) May/.June 2000, page 55. However, the large number of reflections required for much of the light to leave is disadvantageous.

The present invention provides light emitting structure comprising a light emitting diode supported on a substrate, wherein the side of the diode remote from the

substrate is provided with an additional layer in which is formed a diffractive or interference optical element of varying thickness.

The additional layer preferably has a refractive index differing from the adjacent LED layer by no more than 1, more preferably no more than 0.5, even more preferably no more than 0.3, and most preferably, the refractive index of the additional layer substantially equals that of the adjacent LED layer, e.g. by being made of the same material.

In contrast with the prior art mentioned above, the diffractive or interference element has a regular structure, and is formed in an additional layer over and above that required for formation of the LED itself, for example by etching or ion beam milling.

Preferably the LED is an infra-red LED. The LED may be of indium antimonide.

Preferably the diffractive element is a three dimensional grating (regions of differing heights with differing periodicities - equivalent to the superposition of two or more one or two dimensional gratings). However, it could be a simple one or two dimensional linear grating. A suitable interference element is a Fresnel lens, for example.

The diffractive or interference element may be in digital form, i.e. adjacent regions take discrete values of thickness. There may be only two such values, i.e. a binary structure, but preferably more levels, for example 3, 4, or even 8 are provided.

The additional layer may be of germanium. It may be between 2 and 15 microns thick, more preferably between 4 and 10 microns, and most preferably between 6 and 8 microns.

The invention extends (a) to a method of making a light emitting diode structure, comprising forming a light emitting diode on or in a substrate, and depositing a further layer on the outer surface of the diode, said further layer providing a varying thickness diffractive or interference element; and (b) to a method of adapting a light emitting structure including a light emitting diode formed in or on a substrate, the method comprising securing a further layer on the outer surface of the diode, the

further layer being shaped to provide a varying thickness diffractive or interference element.

Further details and advantages of the invention will become apparent upon a reading of the appended claims, to which the reader is referred, and upon a consideration of the following description of embodiments of the invention made with reference to the accompanying drawing, in which Figure 1 shows an embodiment of the invention in diagrammatic cross-section.

In Figure 1 an InSb LED mesa 1 is formed upon (and normally integrally with) a semiconductor substrate 2, the latter in turn being supported upon a further substrate 3. The top surface of the LED mesa is provided with a further layer 5 of germanium on the outer surface of which is formed a diffractive optical element 4 such as a three dimensional grating. The element 4 has a 4 level digitised structure, and theoretically it is possible to extract up to 80% of light from the LED compared with around 30% for a two-level structure.

The layer 5 may be formed integrally with the LED structure during manufacture, for example by deposition of a final germanium layer after formation of the LED mesa or even during processing steps leading to the formation of the light emitting diode.

Alternatively it could be formed separately and secured to the LED mesa, for example by the use of a layer of optically transparent adhesive which is sufficiently thin to allow effective optical contact between the layer 5 and the LED, using adapted tooling and a controlled pressure. In this case the diffractive element could be formed either before or after the adhesion step.

The shaped layer 5 will commonly be provided with an antireflection coating.

By "optical contact" is meant that the gap between the device and the element is no greater than one quarter of the LED wavelength inside the material (i.e. vacuum wavelength divided by n), thus providing a condition in which total internal reflection is effectively prevented and permitting light generated within the device to penetrate into the element over a very wide range of incident angles.

CLAIMS

1. A light emitting structure comprising a light emitting diode supported on a substrate, wherein the side of the diode remote from the substrate is provided with an additional layer in which is formed a diffractive or interference optical element of varying thickness.

2. A structure according to claim 1 wherein the additional layer has a refractive index differing from the adjacent LED layer by no more than 1.

3. A structure according to claim 1 wherein the additional layer has a refractive index differing from the adjacent LED layer by no more than 0.5.

4. A structure according to claim 1 wherein the refractive index of the additional layer substantially equals that of the adjacent LED layer.

5. A structure according to claim 4 wherein the additional layer and the adjacent LED layer are of the same material.

6. A structure according to any preceding claim wherein the light emitting diode is an infra-red emitter.

7. A structure according to claim 6 wherein the light emitting diode emits at a wavelength in the 3 to 12 micron range.

8. A structure according to any preceding claim wherein the light emitting diode is of indium antimonide or an indium antimonide alloy.

9. A structure according to any one of claims 1 to 4, 6 to 8 wherein the additional layer is of germanium.

10. A structure according to any preceding claim wherein the diffractive element is a three dimensional grating.

11. A structure according to any one of claims 1 to 9 wherein the interference element is a Fresnel lens.

12. A structure according to any preceding claim wherein adjacent regions of the diffractive or interference element take discrete values of thickness.

13. A structure according to claim 12 wherein there are two said values.

14. A structure according to claim 13 wherein there are four said values.

15. A structure according to any preceding claim wherein the additional layer is between 2 and 15 microns thick.

16. A method of making a light emitting diode structure, comprising forming a light emitting diode on or in a substrate, and depositing a further layer on the outer surface of the diode, said further layer providing a varying thickness diffractive or interference element.

17. A method according to claim 16 wherein said element is formed subsequent to the formation of the light emitting diode.

18. A method of adapting a light emitting structure including a light emitting diode formed in or on a substrate, the method comprising securing a further layer on the outer surface of the diode, the further layer being shaped to provide a varying thickness diffractive or interference element.

19. A method according to claim 18 wherein the further layer is shaped prior to said securing step.

20. A light emitting diode structure substantially as hereinbefore described with reference to the accompanying drawing.

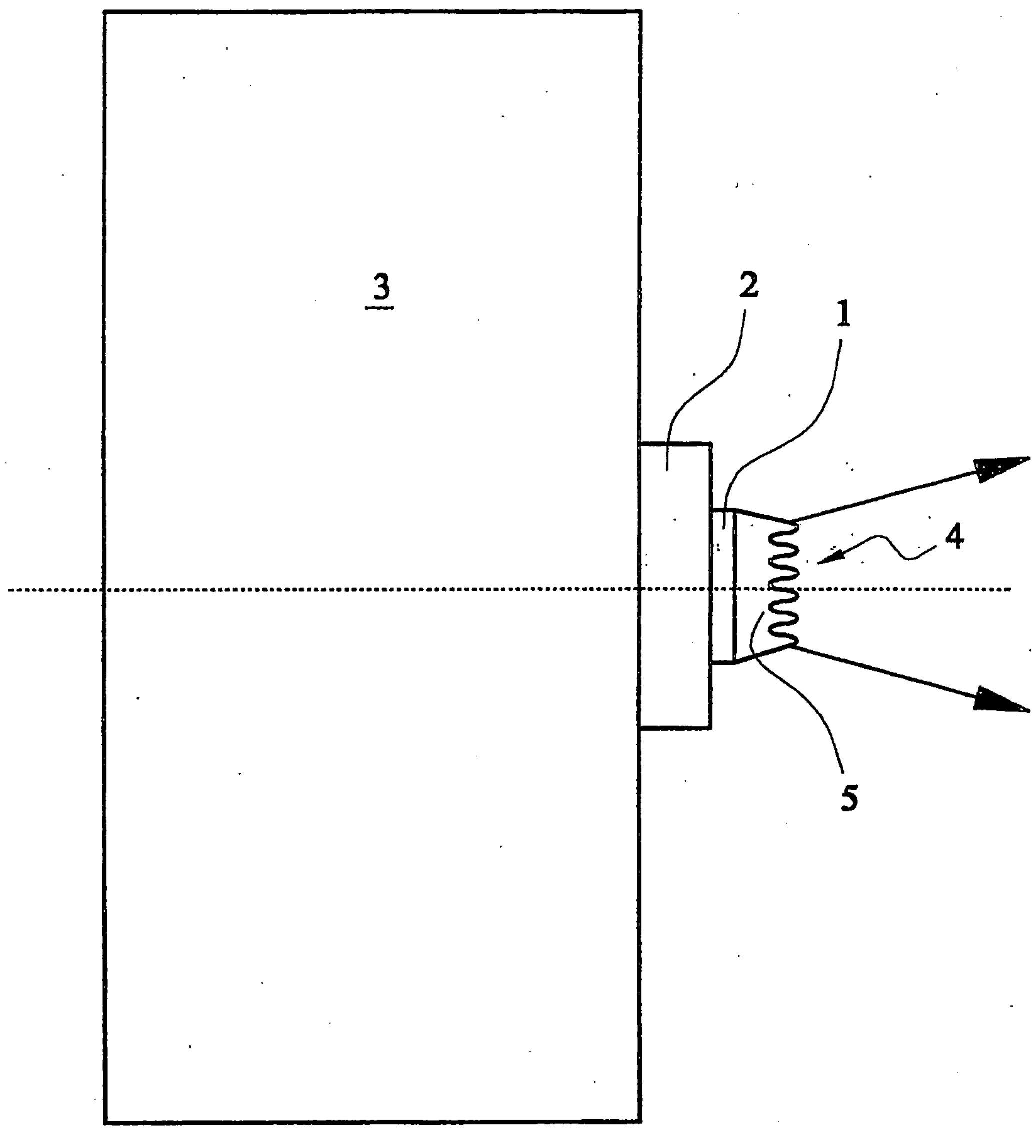

FIG. 1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/03225

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L33/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 22 09 194 A (LICENTIA GMBH) 30 August 1973 (1973-08-30) claim 4; figure 4	1,11, 18-20
X	US 5 181 220 A (YAGI TETSUYA) 19 January 1993 (1993-01-19) column 3, line 21-26; claim 1; figures	1,12,16, 17
A	PATENT ABSTRACTS OF JAPAN vol. 1995, no. 09, 31 October 1995 (1995-10-31) & JP 07 162037 A (TOSHIBA CORP), 23 June 1995 (1995-06-23) abstract	1-5,16, 17,20

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 October 2001	31/10/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Laere, A

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 017, no. 570 (E-1448), 15 October 1993 (1993-10-15) & JP 05 167101 A (TOSHIBA CORP), 2 July 1993 (1993-07-02) abstract ---	1-5,16, 17,20
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Inte nal Application No

PCı/ษB 01/03225

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